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Pinarbasi

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(54) **METHOD FOR MANUFACTURING MTJ
MEMORY DEVICE**

USPC 257/20, 414, 421–427, E29.323;
365/157–158, 171–173; 360/324–326,
360/313; 438/3

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See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this
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(51) **Int. Cl.**
H01L 29/82 (2006.01)
H01L 43/12 (2006.01)
H01L 43/10 (2006.01)

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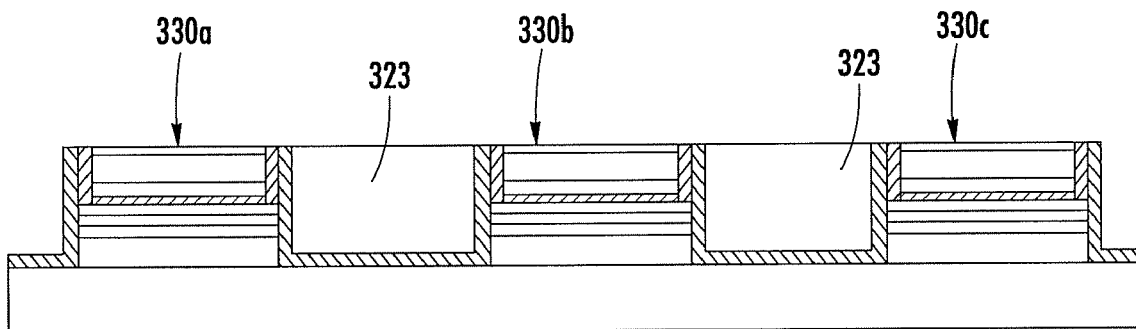
ABSTRACT

(52) **U.S. Cl.**
CPC **H01L 43/12** (2013.01); **H01L 43/10**
(2013.01)

A method for manufacturing MTJ pillars for a MTJ memory device. The method includes depositing multiple MTJ layers on a substrate, depositing a hard mask on the substrate and coating a photoresist on the hard mask. Further, alternating steps of reactive ion etching and ion beam etching are performed to isolate MTJ pillars and expose side surfaces of the MTJ layers. An insulating layer is applied to protect the side surfaces of the MTJ layers. A second insulating layer is deposited before the device is planarized using chemical mechanical polishing.

(58) **Field of Classification Search**
CPC H01L 43/08; H01L 29/82; H01L 23/5226;
H01L 23/528; H01L 27/222; H01L 43/065;
G11C 11/16

21 Claims, 10 Drawing Sheets



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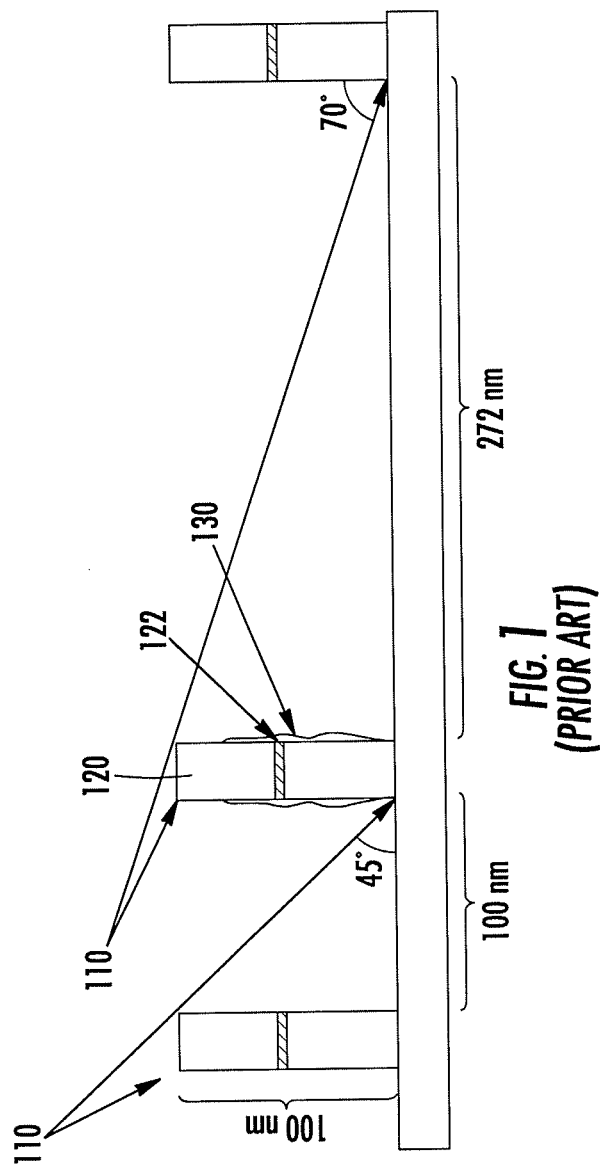
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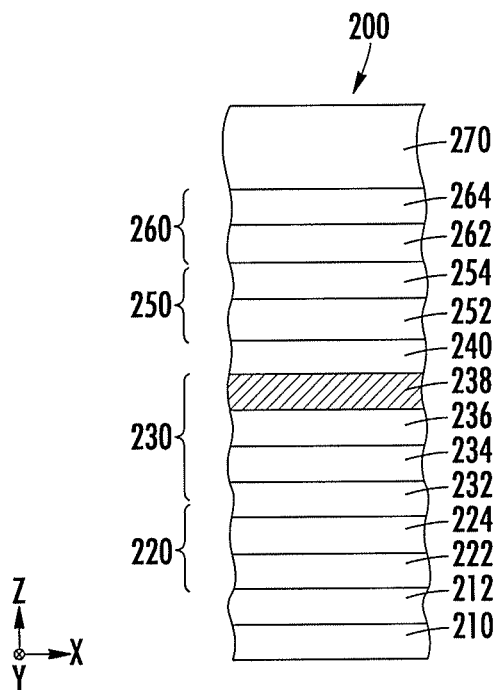


FIG. 2

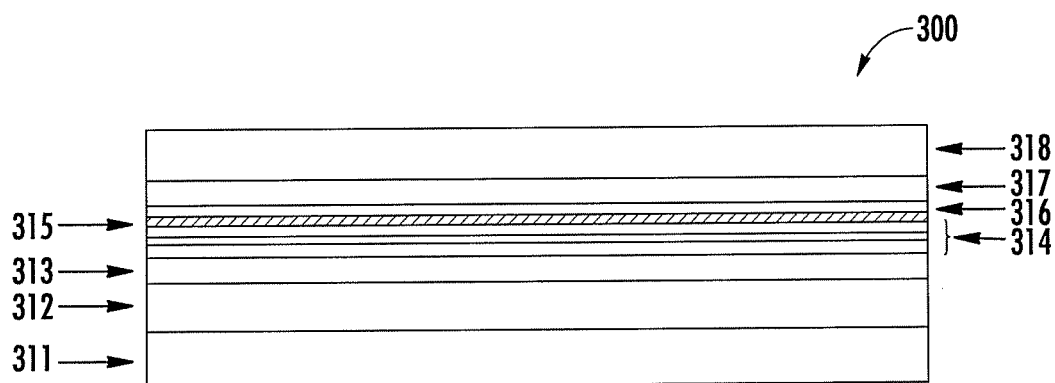


FIG. 3

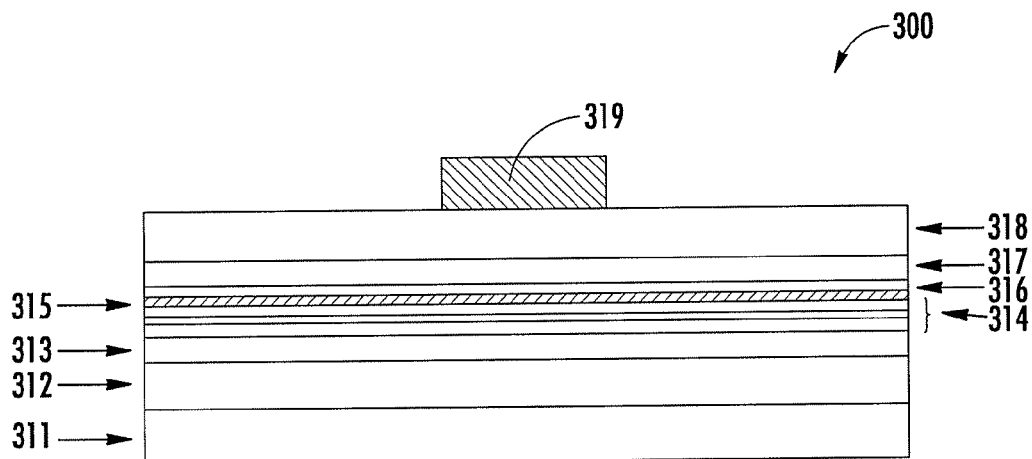


FIG. 4

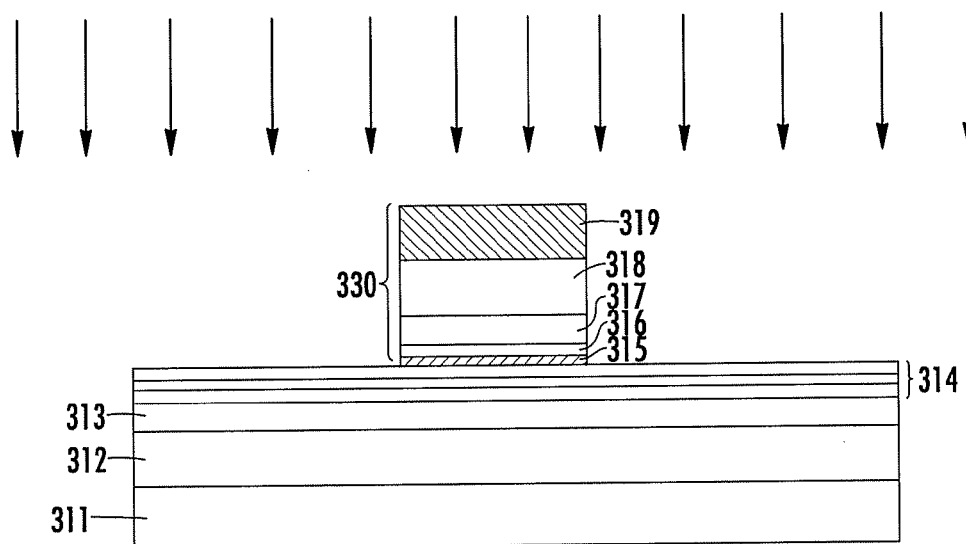


FIG. 5A

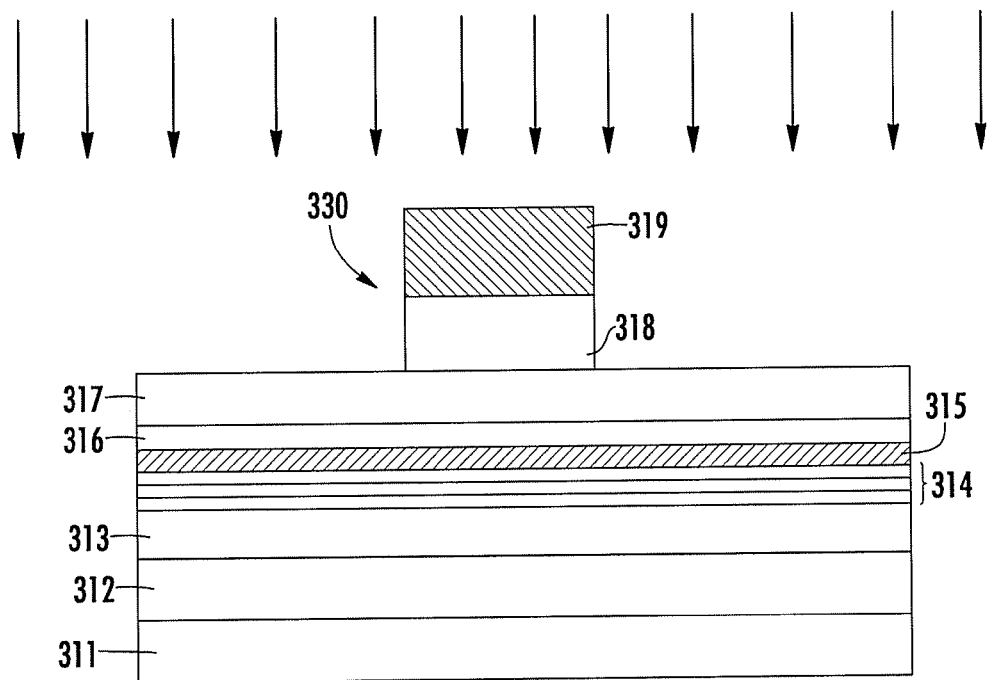


FIG. 5B

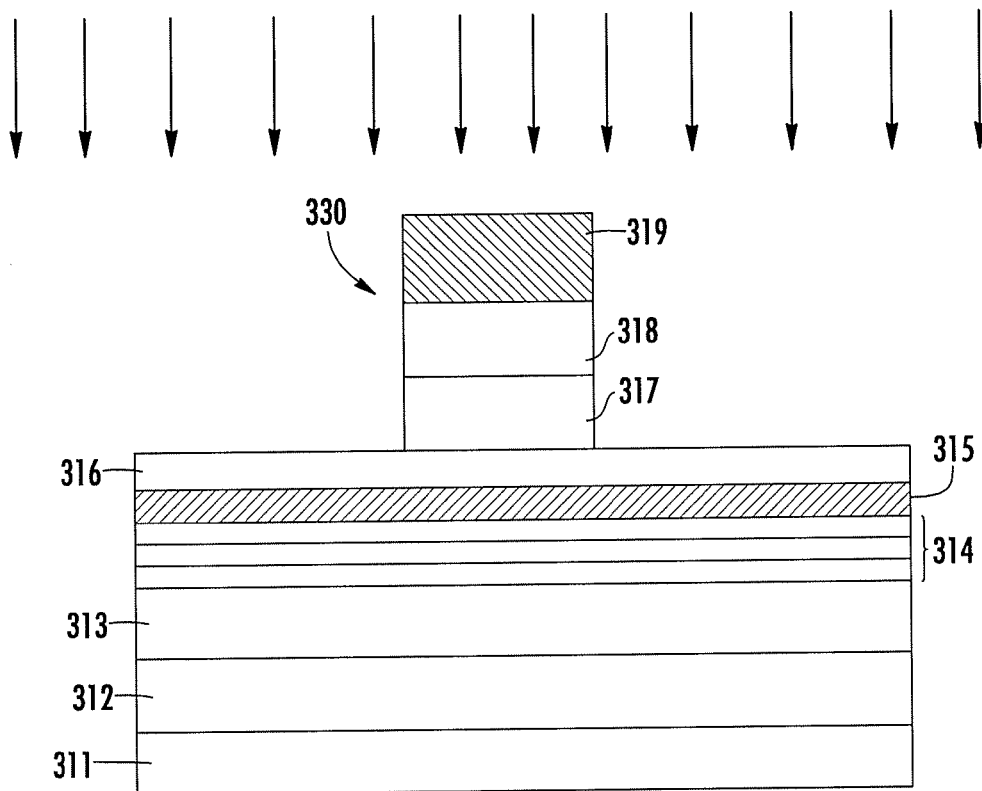


FIG. 5C

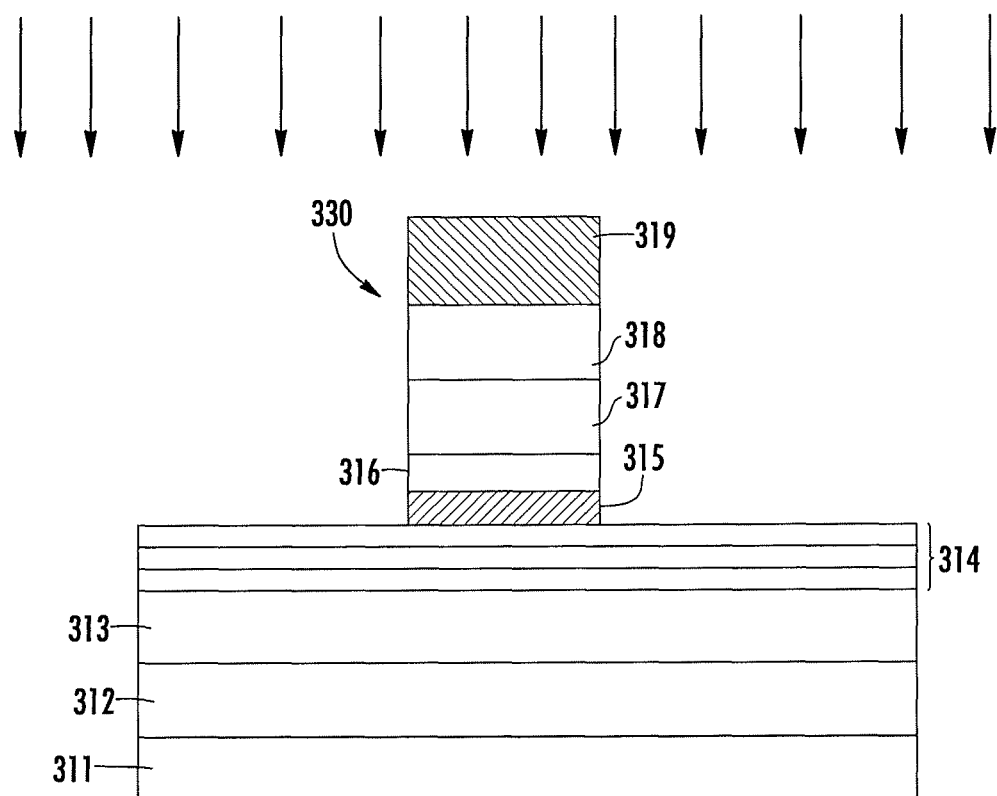


FIG. 5D

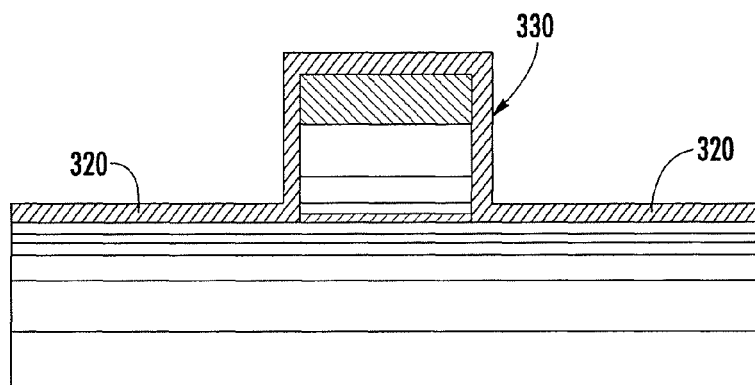


FIG. 6

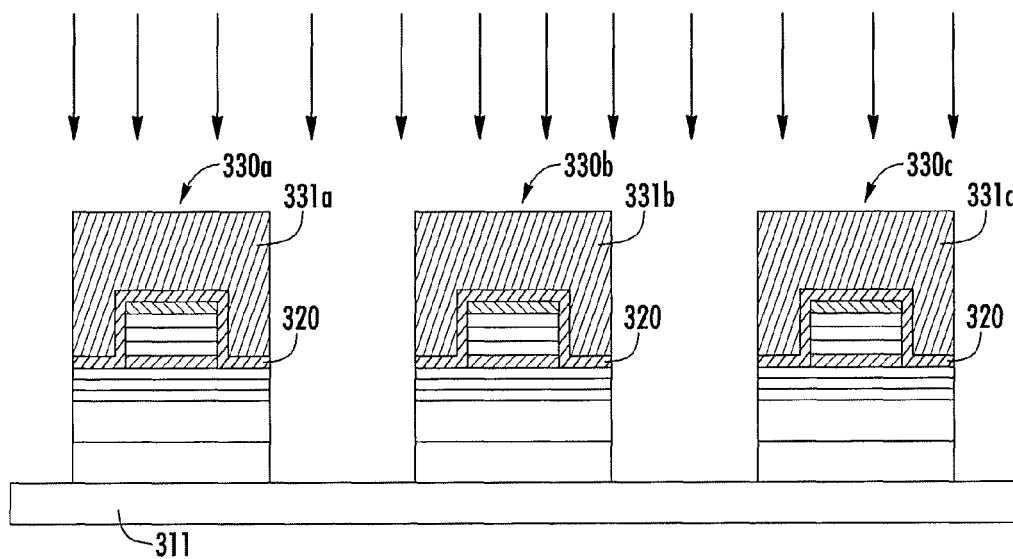


FIG. 7

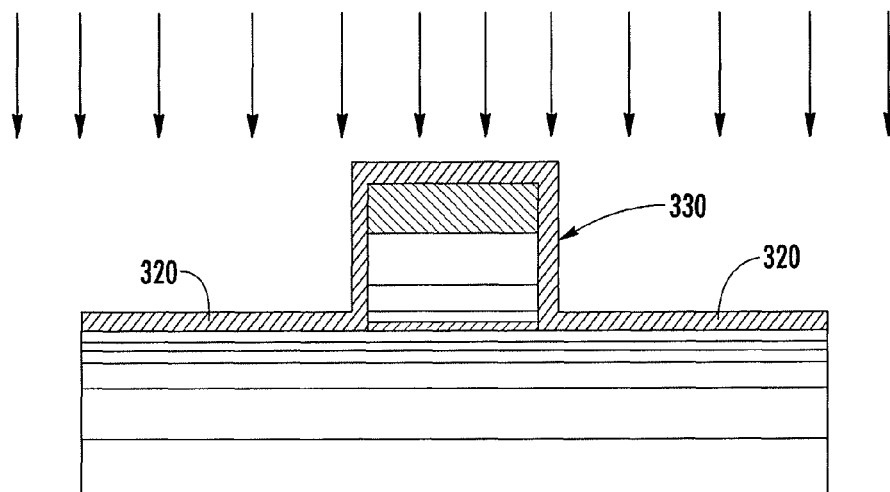


FIG. 8A

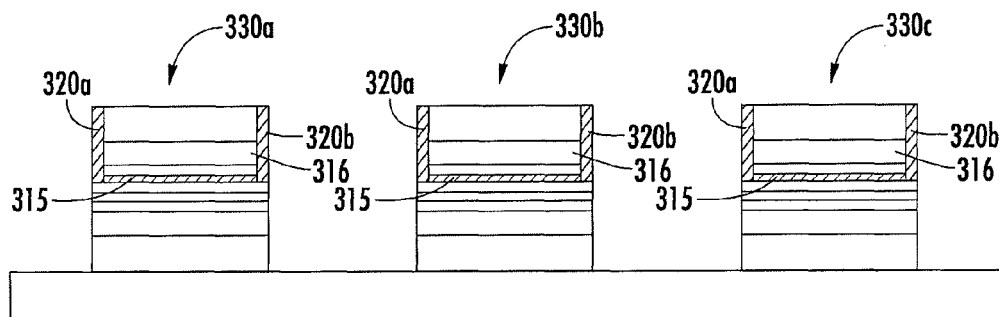


FIG. 8B

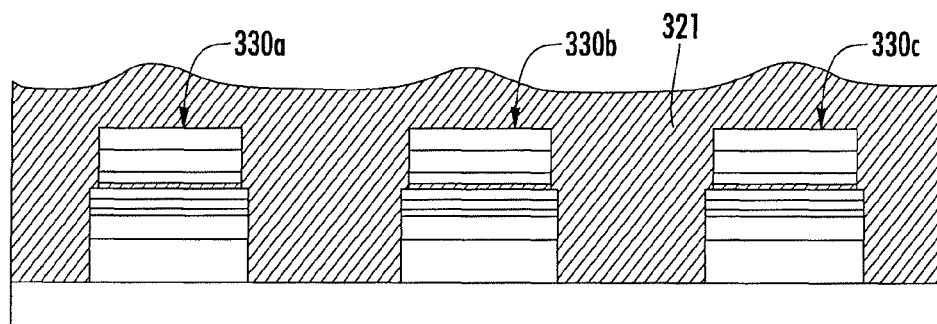


FIG. 9

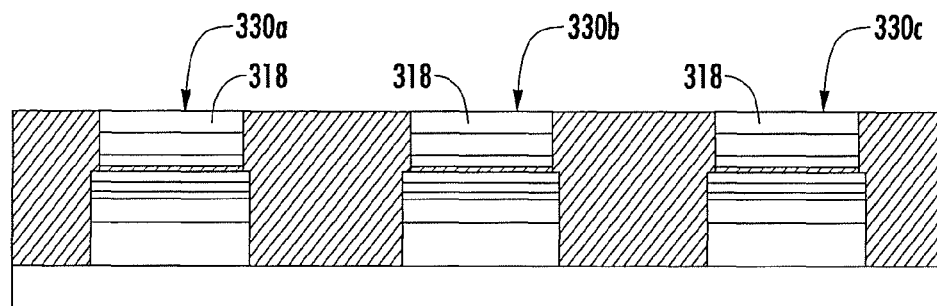


FIG. 10

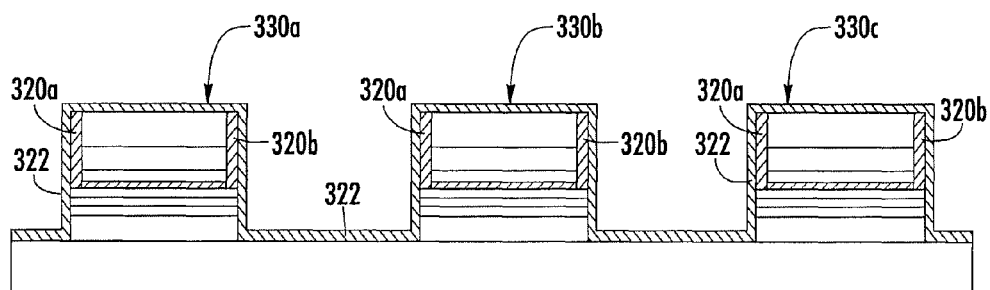


FIG. 11A

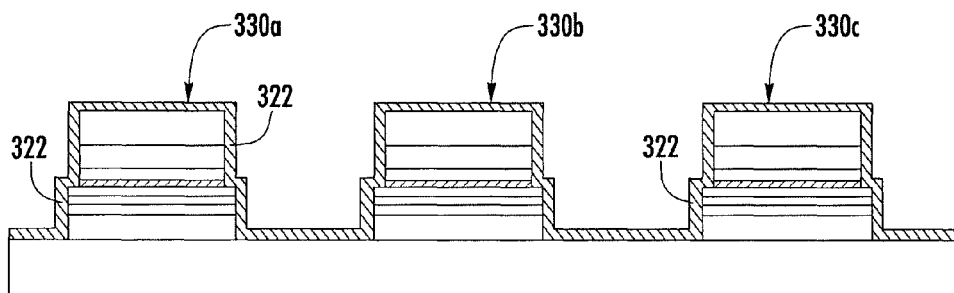


FIG. 11B

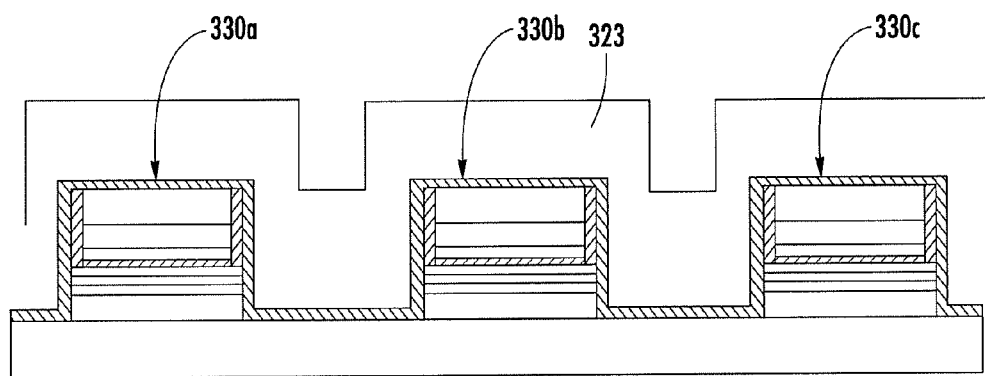


FIG. 12

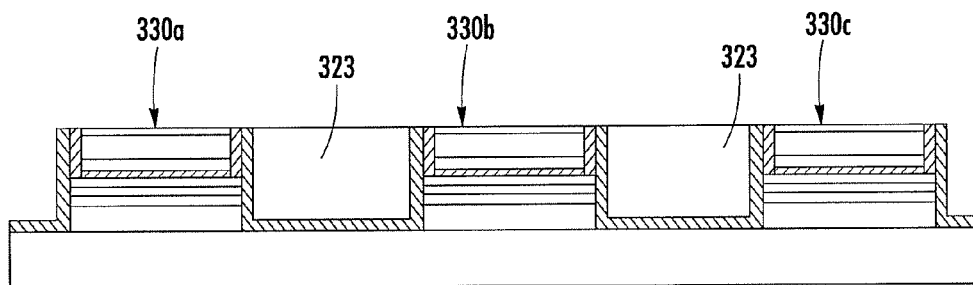


FIG. 13

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METHOD FOR MANUFACTURING MTJ MEMORY DEVICE

STATEMENT OF RELATED CASE

This is a continuation of application Ser. No. 14/341,185, filed Jul. 25, 2014, now U.S. Pat. No. 9,263,667. application Ser. No. 14/341,185 is incorporated herein by reference.

BACKGROUND

1. Field

The present patent document relates generally to a method for manufacturing MRAM devices, and, more particularly, to a method for manufacturing MTJ pillars for MTJ memory devices with improved density and quality specifications.

2. Description of the Related Art

Magnetoresistive random-access memory (“MRAM”) is a non-volatile memory technology that stores data through magnetic storage elements. These elements are two ferromagnetic plates or electrodes that can hold a magnetic field and are separated by a non-magnetic material (i.e., a barrier layer), such as a non-magnetic metal or insulator. In general, one of the plates has its magnetization pinned (i.e., a “reference layer”), meaning that this layer has a higher coercivity than the other layer and requires a larger magnetic field or spin-polarized current to change the orientation of its magnetization. The second plate is typically referred to as the free layer and its magnetization direction can be changed by a smaller magnetic field or spin-polarized current relative to the reference layer.

MRAM devices store information by changing the orientation of the magnetization of the free layer. In particular, based on whether the free layer is in a parallel or anti-parallel alignment relative to the reference layer, either a “1” or a “0” can be stored in each MRAM cell. Due to the spin-polarized electron tunneling effect, the electrical resistance of the cell changes due to the orientation of the magnetic fields of the two layers. The cell’s resistance will be different for the parallel and anti-parallel states and thus the cell’s resistance can be used to distinguish between a “1” and a “0”. One important feature of MRAM devices is that they are non-volatile memory devices, since they maintain the information even when the power is off.

MRAM devices are considered to be the next generation structures for a wide range of memory applications. The magnetic tunnel junction (“MTJ”) layer stack and processing of the MTJ layer stack into pillars for MTJ memory devices are the two most critical aspects of the MRAM technology development. However, under conventional manufacturing schemes, forming pillar like MTJ devices without shunts and at a DRAM-like density is not manufacturable.

One limitation of the current processing technology is illustrated in FIG. 1. Once the photomask and hard mask are formed, the MTJ stack is etched using directional ion beams. During the etching process, the material that is removed from the base of the MTJ pillar **120** is re-deposited on the side of the MTJ pillar. This re-deposited material **130** contains metals such as iridium (Ir), platinum (Pt), ruthenium (Ru) metals and that do not form insulating oxides. As a result, their presence at the edges **122** of the barrier layer of the MTJ pillar **120** is significantly detrimental to the operation of the device. Specifically, this conductive re-deposited material **130** shorts the barrier and renders the tunnel junction of the MTJ structure inoperable. Conventional manufacturing processes alleviate this problem by performing side cleaning at very high ion beam angles (usually 70°) to remove the re-

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deposited material **130** on the sides **122** of the barrier layer of the MTJ pillar. However, this removal process puts unacceptable limits on the device density. For example, as shown in FIG. 1, for an MTJ device structure of 100 nm, the ion beam cleaning requires spacing of approximately 270 nm, which is significantly larger than the density requirements of 100 nm or less between adjacent MTJ pillars. Furthermore, sidewall cleaning at high ion beam angles significantly increases the beam damage to the thin MTJ layers, which only further compromises the MTJ performance. Although the MRAM development companies have spent significant resources and effort to develop ion beam cleaning techniques as well as other manufacturing processes, such as reactive ion etching, the existing manufacturing processes have not lead to a satisfactory process and tooling technology for MTJ pillars.

Accordingly, there is a strong felt need for a manufacturing method for MTJ pillars for a MTJ memory device that meets density and quality requirements for future MTJ memory product application.

SUMMARY

MTJ pillar formation processing steps and a manufacturing method is provided that addresses these critical MRAM device processing issues being faced today. The manufacturing method contemplated herein uses a combination of thin insulator layers and ion beam etching and reactive ion etching to define MTJ pillars. The method includes depositing multiple MTJ layers on a substrate, depositing a hard mask on the substrate and coating a photoresist on the hard mask. Further, alternating steps of reactive ion etching and ion beam etching are performed to isolate MTJ pillars and expose side surfaces of the MTJ layers. An insulating layer is applied to protect the side surfaces of the MTJ layers. A second insulating layer is deposited before the device is planarized using chemical mechanical polishing.

The disclosed method solves the problem of conventional MTJ device manufacturing by reducing the re-deposition of material on the sides of the MTJ pillar, preventing shunts from being formed at the edges of the tunnel barrier layer, and reducing damage caused at the edges of the MTJ layers by using high angle ion beam cleaning.

Through the use of discrete ion beam etching steps, the manufacturing method disclosed herein limits or eliminates the need for high angle ion beam cleaning, provides a processing method that solves one of the biggest manufacturing hurdles with MTJ MRAM technology—processing of high density or closely spaced MTJ pillars—and enables the use of current process tooling/technology to define the MTJ pillars.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are included as part of the present specification, illustrate the presently preferred embodiments and, together with the general description given above and the detailed description given below, serve to explain and teach the principles of the MTJ device manufacturing methods described herein.

FIG. 1 illustrates a conventional manufacturing method of an MTJ device.

FIG. 2 illustrates an exemplary MTJ layer stack (orthogonal spin transfer MTJ) used in accordance with an exemplary embodiment of the manufacturing method described herein.

FIGS. 3-13 illustrate cross-sectional views of selected processing steps of the manufacturing method according to exemplary embodiment described herein.

The figures are not necessarily drawn to scale and the elements of similar structures or functions are generally represented by like reference numerals for illustrative purposes throughout the figures. The figures are only intended to facilitate the description of the various embodiments described herein; the figures do not describe every aspect of the teachings disclosed herein and do not limit the scope of the claims.

DETAILED DESCRIPTION

A method for manufacturing magnetic tunnel junction (“MTJ”) memory devices is disclosed herein. Each of the features and teachings disclosed herein can be utilized separately or in conjunction with other features and teachings. Representative examples utilizing many of these additional features and teachings, both separately and in combination, are described in further detail with reference to the attached drawings. This detailed description is merely intended to teach a person of skill in the art further details for practicing preferred aspects of the present teachings and is not intended to limit the scope of the claims. Therefore, combinations of features disclosed in the following detailed description may not be necessary to practice the teachings in the broadest sense, and are instead taught merely to describe particularly representative examples of the present teachings.

In the following description, for purposes of explanation only, specific nomenclature is set forth to provide a thorough understanding of the MTJ memory device and the method for manufacturing the same as described herein. The various features of the representative examples and the dependent claims may be combined in ways that are not specifically and explicitly enumerated in order to provide additional useful embodiments of the present teachings. It is also expressly noted that all value ranges or indications of groups of entities disclose every possible intermediate value or intermediate entity for the purpose of original disclosure, as well as for the purpose of restricting the claimed subject matter. It is also expressly noted that the dimensions and the shapes of the components shown in the figures are designed to help to understand how the present teachings are practiced, but not intended to limit the dimensions and the shapes shown in the examples.

FIG. 2 illustrates an exemplary MTJ layer stack **200** for an MTJ memory device contemplated herein. The exemplary MTJ layer stack **200** is described in detail in application Ser. No. 14/242,419, filed on Apr. 1, 2014, the contents of which are hereby incorporated by reference. It should be appreciated that the exemplary manufacturing methods described herein are provided to manufacture MTJ memory devices from MTJ layer stack **200**. However, the exemplary processes described herein could be applied to manufacture MTJ memory devices having alternative layer stacks.

As shown in FIG. 2, MTJ layer stack **200** includes one or more seed layers **210** provided at the bottom of stack **200** to initiate a desired crystalline growth in the above-deposited layers. Above the seed layers **210** is a pinning layer **212** and a synthetic antiferromagnetic (“SAF”) structure **220**. According to an exemplary embodiment, pinning layer **212** is platinum manganese PtMn alloy and SAF structure **220** is composed of three layers, layer **222**, layer **224** and the reference layer **232** (discussed below). Preferably, layer **222** is a cobalt iron alloy and layer **224** is a ruthenium metal. An MTJ structure **230** is formed on top of the SAF structure **220**. The MTJ structure **230** includes three separate layers, namely, reference layer **232** formed in the SAF structure **220**, barrier layer **234**, and free layer **236**. In the exemplary embodiment, reference layer **232** and free layer **236** are cobalt-iron-boron

(Co—Fe—B) alloy thin films. Furthermore, barrier layer **234** is formed from an oxide of magnesium MgO. As shown, the MgO barrier layer **234** is disposed between the reference layer **232** and free layer **236** and serves as the insulator between the two layers as discussed above.

As further shown in FIG. 2, a very thin layer of tantalum nitride TaN capping material **238** is disposed on top of the free layer **236**. MTJ layer stack **200** further includes a nonmagnetic spacer **240** disposed on the TaN capping material **238** and perpendicular polarizer **250** disposed on the nonmagnetic spacer **240**. Perpendicular polarizer **250** comprises two laminate layers **252** and **254** and is provided to polarize a current of electrons (“spin-aligned electrons”) applied to the MTJ device, which in turn can change the magnetization orientation of free layer **236** of the MTJ structure by the torque exerted on free layer **236** from polarized electrons carrying angular momentum perpendicular to the magnetization direction of the free layer **236**. The nonmagnetic spacer **240** is provided to insulate perpendicular polarizer **250** from MTJ structure **230**. In addition, one or more capping layers **260** (i.e., layers **262** and **264**) are provided on top of perpendicular polarizer **250** to protect the layers below of MTJ layer stack **200**. A hard mask **270** is deposited over capping layers **260** and may comprise a metal such as tantalum Ta.

FIGS. 3-13 illustrate cross sectional views of selected process stages of the manufacturing of an MTJ memory device composed of MTJ layer stack **200** according to exemplary embodiment of the fabrication method disclosed herein. The cross sectional views in the figures are generally taken through the approximate center of the memory cell in a plane perpendicular to the wafer surface. It should be appreciated that although only one or a few MTJ pillars are shown in the figures, the method may be used for the fabrication of many devices in arrays on a wafer. Furthermore, a plurality of arrays with associated circuitry can be made on a single wafer, which can then be cut into smaller chips for further processing into final operational devices.

FIG. 3 is a sectional view illustrating the initial layering steps for the method of manufacturing an MTJ memory device according to an exemplary embodiment. FIG. 3 illustrates a formation of an MTJ layer structure **300** that corresponds to MTJ layer stack **200** described above with respect to FIG. 2. As will be further explained, certain layers of MTJ structure **200** described above are not illustrated in detail in FIG. 3.

As shown in FIG. 3, a substrate **311** is provided and the additional layers of the MTJ layer stack are deposited on the substrate **311** using a deposition technique, such as thin film sputter deposition or the like. From bottom up, lower layers/bottom contact **312** can be deposited on the substrate **311**, with lower layers/bottom contact **312** including one or more seed layers (e.g., seed layer **210** of FIG. 2) to initiate a desired crystalline growth in the above-deposited layers. Further, an antiferromagnetic layer **313** (e.g., pinning layer **212** of FIG. 2) is deposited on lower layers/bottom contact **312** and synthetic antiferromagnetic layers **314** (e.g., layers **222**, **224** and reference layer **232** of FIG. 2) are deposited on antiferromagnetic layer **313**. A barrier layer **315** (i.e., barrier layer **234** of FIG. 2) is deposited on the synthetic antiferromagnetic layer **314** and free layer **316** (i.e., free layer **236** of FIG. 2) is deposited on barrier layer **315**. As noted above, reference layer **232**, barrier layer **234**, and free layer **236** collectively form the MTJ structure with a very thin TaN capping layer **238** formed on the free layer **236**. As further shown in FIG. 3, upper layers **317**, which can include nonmagnetic spacer **240**, perpendicular polarizer **250** and one or more capping layers **260** shown in FIG. 2, are deposited on the TaN capping layer

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238. Once all of the layers of the MTJ stack are deposited on the substrate 311, a hard mask 318 (e.g., hard mask 270 of FIG. 2) is deposited over the upper layers 317 and is provided to pattern the underlying layers of the MTJ layer stack using a reactive ion etch ("RIE") process, as will be described below. It is reiterated that FIGS. 2 and 3 describe the same MTJ layer stack with the only difference being that some of the individual layers shown in FIG. 2 have been combined as a single layer in FIG. 3 for clarity purposes.

After forming the layer stack of FIG. 3, the manufacturing method proceeds with a next step of coating a photoresist 319 on the hard mask 318, which is patterned or developed to leave the photoresist 319 covering a portion of the hard mask 318 where the MTJ pillar for the MTJ memory device is to be formed. Preferably, the photoresist 319 is exposed with an electron beam or other photolithography tool. The critical dimensions of the photoresist 319 can be reduced using a reductive reactive ion etching process or the like if deep ultraviolet light is to be used.

FIGS. 5A and 5B-5D illustrate two alternative embodiments for etching the MTJ layer stack to the barrier layer 315 of the MTJ structure. In particular, FIG. 5A illustrates a first embodiment of the etching step. As shown, the etching step results in formation of MTJ pillar 330 having a width defined by the width of photoresist 319. As noted above, in the exemplary embodiment, the barrier layer 315 is formed from an oxide of magnesium (MgO). It should be appreciated that processing of MTJ layer stack into MTJ pillar shaped devices requires precise control of the etching depth through all of the stack layers. The barrier resistance control is partially determined based on precision of the etching on the free layer 316 and the barrier layer 315. To eliminate shunting and to reduce the free layer 316 edge damage, stopping at the barrier layer 315 across the wafer is necessary to eliminate the re-deposition on the barrier layer 315. Furthermore, it should be appreciated that stopping at the barrier layer 315 is more difficult if more layers need to be etched to reach the free layer 316, as is the case with OST-MTJ structures.

As noted above, FIG. 5A illustrates a first embodiment in which a step of ion milling is performed to etch the MTJ layer stack to the barrier layer 315. The etching step results in formation of MTJ pillar 330 having a width defined by the width of photoresist 319. In this first embodiment, after the MTJ layer stack is ion milled, the fabrication process proceeds to a deposition of a thin conformal insulator as will be described below with respect to FIG. 6.

FIGS. 5B-5D illustrate a second embodiment for etching the MTJ layer stack according to the exemplary embodiment. In particular, FIGS. 5B-5D illustrate etching using multiple ion beam etching and reactive ion etching techniques (both shown in FIG. 5B-5D as downward facing arrows for illustrative purposes). First, after photoresist 319 is applied as shown in FIG. 4, the hard mask 318 is etched using reactive ion etching and the upper layers 317, including perpendicular polarizer 250, down to TaN capping layer 238 (which is illustrated as part of upper layers 317) are etched using ion beam etching. These two etching steps are collectively shown in FIG. 5B.

It should be appreciated that similar manufacturing methods for MTJ pillars have not been developed for layer stacks having perpendicular polarizers 250 and the like. Therefore, conventional manufacturing methods do not contemplate a separate ion beam etching after the photoresist 319 has been etched using reactive ion etching. In the exemplary embodiment of FIG. 5B, the ion beam etching is stopped at the TaN capping layer 238 using secondary ion mass spectroscopy ("SIMS") end point detection.

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In one further embodiment after the etching shown in FIG. 5B, an insulator layer is deposited on the wafer to protect the edges of the perpendicular polarizer 250 after the ion beam etching is stopped at the end of the perpendicular polarizer 250. Once the insulator layer is deposited, reactive ion etching of the insulator is performed on planar surfaces preferably using inductively coupled plasma etchers, although it should be appreciated that the planar etching can also be performed using other chemical or physical ion beam etching techniques. The etching terminates with the removal of the insulating material on the planar surface. This isotropic etching leaves the protective insulator on the sidewalls of the perpendicular polarizer 250.

Referring back to FIG. 5B, after the ion beam etching of the upper layers 317 to the TaN capping layer 238 (which is part of the upper layers 317), a reactive ion etching is performed to remove the remaining TaN capping layer 238 as shown in FIG. 5C. This reactive ion etching planarizes the wafer so that all previous etch and thickness non-uniformity is eliminated since the reactive ion etching stops at the free layer 316. As noted above, the free layer 316 (also shown in FIG. 2 as free layer 236) is composed of a cobalt-iron-boron (Co—Fe—B) alloy thin film. Thus, the free layer 316 will serve as an etch stop for this second step of reactive ion etching.

Next, as shown in FIG. 5D, a second ion beam etching can be performed to etch free layer 316 and barrier layer 315. In the exemplary embodiment, the ion milling is terminated at a desired point (i.e., the MgO barrier layer 315, also shown as barrier layer 234 in FIG. 2) using secondary ion mass spectroscopy ("SIMS") end point detection. In one embodiment, the ion beam etching can end with higher angle etching to ensure a clean and smooth MgO edge of barrier layer 315. Most importantly, the etching should be stopped before conducting material is re-deposited on sides of the barrier layer. When re-deposition cannot be prevented, it is contemplated that the re-deposited material can be removed from the sides of the barrier layer. Preferably, any small amounts of re-deposited material can be removed after the step of ion beam etching by using additional ion beams at shallow angles such as 45° or less. Preferably, the ion mill etching is terminated at the end of the MgO barrier layer 315, which will eliminate the re-deposited material at the barrier edges. In sum, FIGS. 5B-5D illustrate a second embodiment using separate etching steps using alternating ion beam etching and a reactive ion etching processes to etch the various layers to the barrier layer 315.

Whether etching is performed according to the first embodiment (FIG. 5A) or the second embodiment (FIGS. 5B-5D), the next step involves depositing a protective insulating layer 320 on the MTJ pillar 330 as shown in FIG. 6. Preferably, the protective insulating layer 320 is silicon dioxide (SiO₂), silicon nitride (SiN) or the like. In the exemplary embodiment, the protective insulating layer 320 can be conformally deposited on the MTJ pillar 330 using atomic layer deposition ("ALD") or plasma enhanced chemical vapor deposition ("PECVD") method. Importantly, the protective insulating layer 320 is deposited on both the horizontal and vertical surfaces of the MTJ pillar 330, and preferably uniformly or substantially uniformly deposited. In an exemplary embodiment, the protective insulating layer 320 preferably has a thickness between a few nanometers (e.g., 1-2 nanometers) and 100. In one embodiment, the thickness of the protective insulating layer 320 is approximately 10 nm.

It is contemplated that for the manufacturing of MTJ memory device with low density, an additional photoresist step may be formed around the pillar, either with or without

the protective insulating layer, and ion beam etching can be used to isolate the MTJ devices.

After the protective insulating layer **320** is deposited on the MTJ pillar **330** as shown in FIG. 6, the exemplary method performs one of two process steps to isolate each memory device in the MTJ structure. FIG. 7 illustrates one embodiment in which a second photoresist is formed over each MTJ pillar of the device. In particular, photoresists layers **331a**, **331b** and **331c** are formed respectively over MTJ pillars **330a**, **330b**, **330c**. The photoresists layers **331a**, **331b** and **331c** are formed (i.e., deposited, patterned and developed) over the protective insulating layer **320** covering each MTJ pillars **330a**, **330b**, **330c**. In the exemplary embodiment, it is contemplated that each photoresist layer **331a**, **331b** and **331c** has a width that is wider than the original photoresist **319** deposited to form each MTJ pillar as discussed above. As a result, each of the lower layers/bottom contact **312**, the anti-ferromagnetic layer **313** and the synthetic antiferromagnetic layers **314** for each MTJ pillar **330a**, **330b**, **330c** will have a width that is approximately equal to the deposited second photoresist layers **331a**, **331b** and **331c**, and this width is wider than the above deposited layers of each MTJ pillar (i.e., layers **315-319**).

As further shown in FIG. 7, once the second photoresist layer **331a**, **331b** and **331c** are deposited over each MTJ pillars **330a**, **330b**, **330c**, the fabrication method according to this embodiment contemplates performing a step of ion beam etching to etch the synthetic antiferromagnetic layers **314**, the anti-ferromagnetic layer **313** and the lower layers/bottom contact **312** that are not covered by the second photoresist layer **331a**, **331b** and **331c**. As shown, this step of ion beam etching results in isolation between each of the MTJ pillar **330a**, **330b**, **330c**.

FIGS. 8A and 8B illustrate an alternative to the processing step shown in FIG. 7 in which each memory device is formed in the MTJ structure. In particular, FIG. 8A illustrates a step of ion beam etching (shown as downward facing arrows for illustrative purposes) that is performed on the MTJ pillar **330**. Ion beams are applied downward onto the MTJ pillar **330** at a normal angle or near normal angle. In this step, the ion beam etching removes the protective insulating material on horizontal surfaces of the MTJ pillar **330**, but does not etch the side (i.e., vertical) surfaces. As a result, the edges of the barrier layer and the free layer edges are fully protected by the protective insulating material **320a** and **320b** as shown in FIG. 8B. Preferably, the ion beam etching continues until each MTJ pillar is electrically isolated from each adjacent MTJ pillar.

FIG. 8B illustrates the resulting structure of the ion beam etching with three MTJ pillars **330a**, **330b**, **330c**. Due to the protective insulating material **320a** and **320b** on the vertical surfaces of each of the MTJ pillars **330a**, **330b**, **330c**, there is no re-deposition of the etched material on the barrier layer **315** or any damage during this etching step. Moreover, the materials that are hard to remove and cause shunts (e.g., iridium (Ir), platinum (Pt), ruthenium (Ru) metals and the like), are prevented from contacting the barrier layer **315**, which is critical since these metals do not easily oxidize, and, therefore, significantly damage device performance when even trace amounts are re-deposited on the barrier layer **315**. Because protective insulating material **320a** and **320b** completely isolate the edges of the barrier layer **315**, any material that is re-deposited on the side of the insulating layers **320a** and **320b** layer cannot cause shunts. This process eliminates the need for high angle ion mill cleaning, which in turn eliminates the obstruction that conventional manufacturing processes encountered when making high density devices.

Further, it is contemplated that directional reactive etching can be used to remove the protective insulating layer **320** on the horizontal surfaces of the MTJ pillars **330a**, **330b**, **330c**. The directional reactive etching can be followed by the ion beam etching of the remaining MTJ layers or different combinations of these techniques can be used.

Once the ion beam etching is complete (i.e., in either FIG. 7 or FIG. 8A), a new insulating layer **321** is deposited on the MTJ pillars **330a**, **330b**, **330c**, again using an ALD or PECVD method as shown in FIG. 9. Further, it is contemplated that the protective insulating material **320a** and **320b** on the sides of each MTJ pillar **330a**, **330b**, **330c**, can be removed by reactive ion etching before the new insulating layer **321** is deposited in one embodiment.

FIG. 10 illustrates the final processing step of the MTJ pillars by planarizing the wafer resulting in exposure of hard mask **318** of each MTJ pillar **330a**, **330b**, **330c**. Such planarization may be accomplished by conventional chemical mechanical polishing. As should be understood to those skilled in the art, after the CMP step, a top contact layer can then be deposited on the wafers (not shown).

FIGS. 11A-13 illustrate yet another exemplary embodiment of the method of manufacturing an MTJ device for read head applications for hard drives. In particular, FIGS. 11A-13 illustrate alternative steps to those disclosed in FIGS. 9 and 10 discussed above. In other words, the alternative embodiment contemplates the same initial manufacturing steps discussed above that result in three isolated MTJ pillars **330a**, **330b**, **330c**, each with a protective insulating layer covering the edges of the barrier layer **315** and free layer **316**. FIGS. 11A-13 follow the ion beam etching step illustrated in either FIG. 7 or FIGS. 8A-8B and provide a method for controlling a stabilizing magnetic field exerted on the free layer **316**.

First, as shown in FIG. 11A, an insulating layer **322** is deposited over the horizontal and vertical surfaces of each MTJ pillar **330a**, **330b**, **330c**. Preferably, the insulating layer **322** is silicon dioxide (SiO₂), silicon nitride (SiN) or the like. Alternatively, the existing protective insulating material **320a** and **320b** on the edges of the barrier layer can first be removed before insulating layer **322** is deposited, which is illustrated in FIG. 11B. Advantageously, removing the existing protective insulating material **320a** and **320b** before depositing the new insulating layer results in a more precise definition of the thickness of insulating layer **322** that separates free layer **316** and the stabilizing magnetic layer, as discussed below.

In either embodiment, following deposition of the insulating layer **322** (steps illustrated in FIGS. 11A or 11B), a stabilizing magnetic layer **323** is deposited over the insulating layer **322**, as shown in FIG. 12. Finally, FIG. 13 illustrates the final processing step of the MTJ read head device by planarizing the wafer resulting in exposure of hard mask **318** of each MTJ pillar **330a**, **330b**, **330c**. Similar to the exemplary embodiment disclosed above, such planarization may be accomplished by conventional chemical mechanical polishing. As should be understood to those skilled in the art, after the CMP step, another magnetic layer to pin the magnetization of the stabilizing magnetic layer **323** and conductive leads can be deposited on the wafers (not shown). By changing and controlling the thickness of the protective insulating layer **322**, the embodiment described in FIGS. 11A-13 can advantageously modify the stabilizing magnetic field that stabilizes magnetic layer **323**. This manufacturing variation can be important in the operation of the MTJ read head applications for hard drives.

The above description and drawings are only to be considered illustrative of specific embodiments, which achieve the features and advantages described herein. Modifications and substitutions to specific process conditions can be made.

Accordingly, the embodiments in this patent document are not considered as being limited by the foregoing description and drawings.

What is claimed is:

1. A method of manufacturing a magnetic tunnel junction (“MTJ”) device, the method comprising:

depositing a plurality of MTJ layers on a substrate wafer, the plurality of MTJ layers including a reference layer, a barrier layer disposed on the reference layer and a free layer disposed on the barrier layer;

depositing a hard mask above the plurality of MTJ layers; forming a first photoresist layer on a portion of the hard mask;

etching the hard mask and the plurality of MTJ layers to form an MTJ pillar under the first photoresist layer, wherein the free layer and barrier layer are etched to expose side surfaces of the free layer and the barrier layer of the MTJ structure;

depositing a first insulating layer on the MTJ pillar, on the exposed side surfaces of the free layer and the barrier layer, and on an exposed surface of the reference layer;

etching the MTJ pillar to remove portions of the first insulating layer disposed on horizontal surfaces of the MTJ pillar but leaves portions of the first insulating layer on the exposed side surfaces of the free layer and barrier layer, and to electrically isolate the MTJ pillar from adjacent MTJ pillars; and

planarizing the substrate wafer,

wherein the step of etching the hard mask and the plurality of MTJ layers includes at least one reactive ion etching and at least one ion beam etching, wherein the at least one ion beam etching ends with an ion beam etch at a high ion beam angle.

2. The method of manufacturing according to claim 1 wherein the high ion beam angle is seventy degrees.

3. The method of manufacturing according to claim 1, wherein the step of etching the MTJ pillar to remove portions of the first insulating layer is performed using ion beam etching.

4. The method of manufacturing according to claim 1, wherein the step of depositing a plurality of MTJ layers further comprises:

depositing a tantalum nitride capping layer on the free layer; and

depositing a perpendicular polarizer on the tantalum nitride capping layer.

5. The method of manufacturing according to claim 4, wherein the step of etching the hard mask and the plurality of MTJ layers further comprises:

reactive ion etching the hard mask;

ion beam etching the perpendicular polarizer;

reactive ion etching the tantalum nitride capping layer;

ion beam etching the free layer and the barrier layer, wherein the ion beam etching the free layer and the barrier layer step ends with an ion beam etch at a high ion beam angle.

6. The method of manufacturing according to claim 5, wherein the free layer comprises a CoFeB thin film, which serves as an etch stop for the reactive ion etching of the tantalum nitride capping layer.

7. The method of manufacturing according to claim 5, wherein after the step of ion beam etching the perpendicular polarizer, a third insulating layer is conformally deposited on the MTJ pillar.

8. The method of manufacturing according to claim 7, further comprising etching the MTJ pillar to remove a portion of the third insulating layer that is disposed on horizontal surfaces of the MTJ structure.

9. The method of manufacturing according to claim 1, wherein the step of etching the MTJ pillar to remove a portion of the first insulating layer comprises applying ion beams at a normal angle relative to the substrate wafer.

10. The method of manufacturing according to claim 1, further comprising conformally depositing a second insulating layer on the MTJ pillar after the step of ion beam etching the MTJ pillar.

11. The method of manufacturing according to claim 1, wherein the barrier layer comprises an oxide of magnesium.

12. The method of manufacturing according to claim 5, further comprising stopping the ion beam etching of the barrier layer using secondary ion mass spectroscopy end point detection.

13. The method of manufacturing according to claim 1, further comprising forming a second photoresist layer on the first insulating layer on the MTJ pillar before the step of etching the MTJ pillar to remove a portion of the first insulating layer.

14. The method of manufacturing according to claim 13, wherein the second photoresist layer has a width over the MTJ pillar that is larger than a width of the first photoresist layer.

15. A method of manufacturing a magnetic tunnel junction (“MTJ”) device, the method comprising:

depositing a plurality of MTJ layers on a substrate wafer, the plurality of MTJ layers including a reference layer, a barrier layer disposed on the reference layer and a free layer disposed on the barrier layer;

depositing a hard mask above the plurality of MTJ layers; forming a first photoresist layer on a portion of the hard mask;

reactive ion etching the hard mask;

ion beam etching the free layer and the barrier layer to expose side surfaces of the free layer and barrier layer, thereby forming an MTJ pillar, wherein the ion beam etching the free layer and the barrier layer step ends with an ion beam etch at a high ion beam angle;

depositing a first insulating layer on the MTJ pillar, on the exposed side surfaces of the free layer and the barrier layer, and on an exposed surface of the reference layer;

etching to electrically isolate at least one MTJ pillar to leave portions of the first insulating layer on the exposed side surfaces of the free layer and barrier layer; and

planarizing the substrate wafer.

16. The method of manufacturing according to claim 15 wherein the high ion beam angle is seventy degrees.

17. The method of manufacturing according to claim 15 wherein the etching at an angle normal relative to the substrate wafer to isolate at least one MTJ pillar step is performed using ion beam etching.

18. The method of manufacturing according to claim 15, further comprising conformally depositing a third insulating layer after the step of ion beam etching the at least one upper layer.

19. The method of manufacturing according to claim 18, further comprising a further step of reactive ion etching to remove horizontal surfaces of the third insulating layer.

20. The method of manufacturing according to claim 19, further comprising coating a second photoresist layer on the first insulating layer on the MTJ pillar before the step of etching at an angle normal relative to the substrate wafer to isolate at least one MTJ pillar.

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21. The method of manufacturing according to claim **20**, wherein the second photoresist layer has a width over the MTJ pillar that is larger than a width of the first photoresist layer.

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